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On the use of cost–benefit analysis for the evaluation of farm household investments in natural resource conservation

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ABSTRACT. Farm households in developing countries are generally credit constrained. This forces them to simultaneously take production and consumption decisions. In this paper, a two-period lifecycle model of the farm household is constructed and the household's investment response to changes in land and agricultural output prices are derived theoretically. It is shown that in the absence of credit markets household responses to exogenous price changes may differ from the predictions of cost–benefit analysis. Farm household responses are also derived for the case where price increases for land and agricultural output are accompanied by the introduction of a credit market. For this case the results show that farm household reactions are in accordance with predictions made by cost–benefit analysis. An empirical case study from Bénin underscores the relevance of considering access to credit in establishing whether investments in soil conservation are beneficial to farm households.

1. Introduction

Degradation of the natural environment and soil degradation especially are a serious problem in many parts of the world. Oldeman, Hakkeling, and Sombroek (1990) estimate that since 1945 1.2 billion hectares of agricultural land have been moderately or strongly degraded as a result of human activity. It has been argued (e.g., World Bank, 1992) that price distortions have played an important role in encouraging activities that damage the quality of the soil. If this argument is correct, higher prices of land and/or output will increase the value of land conservation efforts, thereby encouraging greater conservation of natural resources. Cost–benefit analysis based on a given time discount rate usually supports this argument.[1]

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[1] Higher prices of land and/or output in the *current* period may actually lead to increased soil mining and land degradation, in spite of higher benefits in *future* periods from land conservation (LaFrance, 1992; Pagiola, 1996). In this paper we will therefore focus on the effect of higher *future* land and/or output prices on land conservation. In this case cost–benefit analysis based on a given time discount rate will point to an unambiguous positive effect on land conservation.

The aim of this paper is to show that the expected results only come about in case of the existence of well-functioning credit markets. In their absence, no straightforward relationship exists between removing price distortions and farmers' incentives to invest in the conservation of their natural capital base. The reason for this is that higher future prices for agricultural produce or land *may increase the discount rate* of farmers who cannot borrow and therefore investment becomes less attractive. This may lead to perverse investment reactions with increased price incentives. Farmers who can borrow face an exogenously given discount rate given by the interest rate, and therefore they are not negatively affected by increased price incentives.

To show this an intertemporal agricultural household model is constructed. The reason for developing this type of model is that it is capable of simultaneously analysing production and consumption decisions. This is required because, in the absence of well-functioning credit markets, agricultural households cannot make investment decisions in isolation of consumption decisions.

The existence of a potential trade-off between farm consumption and investment has long been recognized (Chayanov, 1925; Singh, Squire, and Strauss, 1986; de Janvry, Fafchamps, and Sadoulet, 1991; Phimister, 1995). Also in the environmental literature, a growing body of literature focuses on the interactions between production and consumption decisions by farmers if there are market imperfections. Imperfect credit markets may lead to very high rates of time preference and therefore to less environmental conservation (Holden, Shiferaw, and Wik, 1998). They may also lead to more environmental conservation because the future disutility of degrading the resource is potentially unbounded with a subsistence requirement (Pagiola, 1995). With a missing labour market, investment in conservation will increase with the labour endowment of households (Barbier, 1998) and growth in the non-farm rural sector may have a negative impact on soil conservation (Pender and Kerr, 1998; Romano, 1999). And if risk and insurance markets are missing, poverty may lead to more or less soil conservation (Grepperud, 1997).

This paper contributes to this literature by analysing the effect of price changes on soil conservation within the framework of a non-separable farm household model, and by comparing the results with those derived from cost–benefit analysis. In our discussion we will use the net present value (NPV) criterion or 'standard' definition of the 'cost–benefit approach'. It is this approach which has been used most extensively in project evaluation as well as in evaluating the attractiveness of soil conservation efforts. Although cost–benefit analysis is usually associated with analysis at a fairly aggregated project level, it can also be used at the farm level (Lutz *et al.* 1994, Araya and Asafu-Adjaye, 1999). Standard cost–benefit analysis compares the discounted costs of investments with the discounted benefits from investment. If investments are made in the present, and benefits are derived in the future, then cost–benefit analysis claims that an investment should be made if the current (opportunity) cost of investment is lower than the future discounted (net) benefits from this investment

$$p_0^n < \sum_{t=1}^{T} \frac{1}{(1 + \rho_t)^t} B_t \tag{1}$$

where p_0^n is the cost of investment in period $t = 0$, B_t the (net) benefit from this investment in the future period $t(t = 1, \ldots, T)$, T the last period that the investment generates a benefit, and ρ_t the discount rate in period t. The choice of an appropriate discount rate depends on the presence or absence of market imperfections. If there are no market imperfections (such as the absence of insurance and credit markets, lack of clear property rights, information on prices and technology), then the appropriate discount rate is the exogenously given market rate of interest r_t in period t. If there are market imperfections, then the appropriate discount rate is given by the *shadow price* of time for the household.

The paper shows that even if the future discounted benefits of an investment increase (because B_t increases in formula (1)), the household may actually be *less inclined* to invest, because the household's discount rate varies also with the height of current and future consumption and therefore with future benefits. Only if the increase in benefits weighs up against changes in the discount rate (that is, the changes in the shadow price of time), will it be beneficial to invest. Standard cost–benefit analysis ignores these changes in the discount rate, and therefore may give incorrect prescriptions. The paper develops a model to show under which conditions this might be the case and presents a case study from the Atacora region in Bénin to suggest the empirical relevance of this phenomenon.

The paper is organized as follows. In section 2 reflections are presented on the cost–benefit analysis of soil degradation. The model is constructed in section 3. In section 4 the reactions of a household (i) to increases in the price of land and (ii) to higher agricultural output prices are presented in the absence and presence of credit markets. In section 5 we discuss why the results from the intertemporal model may deviate from the predictions made on the basis of standard cost–benefit analysis. In section 6 we provide an empirical case study from Bénin to illustrate the empirical relevance of our findings. Section 7 concludes.

2. Cost–benefit analysis of soil degradation

Many cultivation practices tend to degrade land over time, reducing its actual or potential uses. Cultivation practices can expose soil to water and wind erosion; repeated tillage can weaken soil structure; crop production can remove nutrients; and use of machinery can lead to soil compaction. Land degradation, in turn, is the cause of stagnating or declining yields and thus threatens the generation of income of the many people whose primary source of income is derived from agriculture.

Typically in analyses on the adoption of conservation measures by farmers, a wide range of factors is included. Pagiola (1996) distinguishes biophysical characteristics and their relation to investment returns and costs; Lutz *et al*. (1994) indicate that the adoption of conservation measures depends on their cost and benefits as determined by agro-ecological conditions, technologies used, prices of inputs used, and outputs produced; Anim (1999) finds that awareness about increases in long-term profits contributes to the adoption of conservation measures, whereas Shively (1997) shows that the combination of increased returns and increased production risk may lead to adoption of conservation technologies by farmers with specific risk preferences. Lapar and Pandey (1999) report that the high cost of establishment, maintenance and loss of land to hedgerows are major constraints for the adoption of these conservation methods in the Philippines. As a consequence these authors call for the development of a 'range of cost-effective technologies'. What these studies have in common is their reliance, implicit or explicit, on a cost–benefit approach.

One of the underlying assumptions of the cost–benefit approach is that production and consumption decisions are taken recursively: the household first optimizes its production decisions and then considers its consumption (and savings) in light of the income obtained from production. In case of investment decisions—which are intertemporal by nature—it requires the existence of credit markets as they allow to temporarily increase the availability of resources through borrowing. Only under these circumstances it is possible to delink the allocation of resources to consumption from decisions on investment outlays.

It is precisely the absence of (credit) markets that characterizes developing countries (Hoff, Baverman, and Stiglitz, 1993). High information, monitoring and transaction costs, lack of collateral following unenforceable property rights, and moral hazard problems all contribute to absent or malfunctioning credit markets in these economies. Imperfect credit markets are not only a characteristic of underdeveloped countries, Miller *et al.* (1993) show that credit restrictions also hold for farms in the European Union.

If there is no credit market the farm household must equate its current income to consumption and investments. In such circumstances predictions based on cost–benefit analysis are no longer incontestably valid. To illustrate this, consider the following example in which farmers are given three options to invest in soil quality: low, medium, or high investment. In period 1 farmers have ten units available which they can either consume or invest. Returns to investment are positive but have decreasing marginal returns. Utility in each period t is a concave function of consumption C_t and given by $\log(C_t/1000)/(C_t/1000)$. We assume that the interest rate and discount rate are 20 per cent, although similar examples can be constructed for different rates.

Panel A of table 1 analyses the investment behaviour if there is no credit market. The first three columns of panel A show that the farmer chooses a medium investment level, giving the highest discounted utility. The last three columns of panel A analyse the investment behaviour after a 100 per cent increase in the output price in period 2. Because of the price doubling, each investment level generates a consumption level which is twice as high in the second period. In this case a utility-maximizing farmer chooses a *lower* investment, because there is less need to invest given the high returns in the second period and the desire to smooth consumption over both periods (because of the concavity of the utility function). However, from the point of view of the NPV criterion a high investment level becomes *more* attractive, as the NPV of high investment is greater than the NPV of any of the other investment options after the price increase. Panel B

Table 1. *Farm household investment in the presence and absence of liquidity constraints*

	No credit market					
	Amount invested			*Price increase: +100% Amount invested*		
	Low (1)	*Medium (2)*	*High (3)*	*Low (4)*	*Medium (5)*	*High (6)*
Panel A						
Consumption period 1	9.0	8.0	7.0	9.0	8.0	7.0
Invested amount	1.0	2.0	3.0	1.0	2.0	3.0
Return on investment	9.0	12.0	13.0	9.0	12.0	13.0
Consumption period 2	9.0	12.0	13.0	18.0	24.0	26.0
NPV investment	6.5	8.0	7.8	14.0	18.0	18.7
NPV additional investment		1.5	**−0.2**		4.0	**0.7**
Discounted utility in ‘000	−0.417	**−0.396**	−0.429	**−0.308**	−0.318	−0.359
MRS	1.00	2.39	3.76	4.44	10.64	16.81
	Credit market					
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
Panel B						
Consumption period 1	9.0	9.8	9.7	13.1	15.3	15.6
Invested amount	1.0	2.0	3.0	1.0	2.0	3.0
Return on investment	9.0	12.0	13.0	9.0	12.0	13.0
Consumption period 2	9.0	9.8	9.7	13.1	15.3	15.6
Borrowed amount	0.0	1.8	2.7	4.1	7.3	8.6
Loan repayment	0.0	2.2	3.3	4.9	8.7	10.4
NPV investment	6.5	8.0	7.8	14.0	18.0	18.7
NPV additional investment		1.5	**−0.2**		4.0	**0.7**
Discounted utility in ‘000	−0.417	**−0.375**	−0.379	−0.264	−0.218	**−0.212**
MRS	1.00	1.00	1.00	1.00	1.00	1.00

Notes: (1) the interest and discount rate are 20%, (2) MRS = marginal rate of intertemporal substitution

analyses the investment behaviour if there is a credit market. In this case the farmer will borrow to smooth consumption across the two periods, and invest according to the NPV criterion. In particular, the farmer will invest *more* after an increase in the output price in the second period in line with the cost–benefit criterion. The last row in each panel reports the marginal rate of intertemporal substitution (MRS) for each investment option. The MRS is constant for the case where there is a credit market but varies across investment options and prices if there is no credit market. In section 5 it will be shown that it is precisely this variation in the MRS which may cause household behaviour to deviate from cost–benefit predictions.

This illustration thus shows that in situations where credit markets are malfunctioning, increases in NPV do not always lead to more investment.

In fact they may make it more attractive to lower investment. To illustrate this result formally, we construct in the next section a model that describes the farmer's intertemporal optimization problem.

3. A model of the farm household

The model begins with a representative household that maximizes an intertemporal utility function which is assumed to be additive with a strictly concave subutility function $U(.)$, defined over consumption in each period. It is assumed that at the beginning of the first period the household plans its consumption and production levels for all periods, both current and future (eq. (2)). Perfect foresight is assumed with regard to prices and yields and we abstain from the incorporation of uncertainty. The model is constructed as a two-period lifecycle model.

In the absence of credit markets, the household is limited in its intertemporal optimization. Only through costly investments in soil conservation is it able to transfer income from the first period to the next at the expense of consumption in the first period. The amount of natural capital is measured in *efficiency units*, which include the quantity of land as well as its quality. Investments in soil conservation amount to adding efficiency units to the natural capital stock, either by increasing the amount of land under cultivation or by improving the quality of the soil. Here we assume that investments focus on the latter, that is investment in the quality of the soil, such as the construction of physical soil conservation structures.

Income is obtained from agricultural production and is generated by utilizing natural capital (land) in a strictly concave production process. Thus in the first period consumption and investment expenditures equal income from agricultural production (eq. (3)). Investment is multiplied by the price per efficiency unit of investment in the quality of the soil to reflect labour cost or expenses for the use of equipment. In the second period, consumption equals income from agricultural production plus the sale of natural capital at the end of the second period (eq. (4)). This is the usual closing condition for household decisions in a lifecycle model. The natural capital stock depreciates over time under the influence of human action at rate α. The total amount of capital stock in the second period equals the depreciated initial capital stock plus investments undertaken to counter or improve on this (eq. (5)).[2]

The model is formulated as follows:

maximize

$$U = U(C_1) + \frac{U(C_2)}{1 + \rho} \tag{2}$$

subject to

$$p_1 f(K_1) = C_1 + p_1^{\mathrm{n}} I_1 \tag{3}$$

[2] Of course farmers often do not invest in more natural capital, but they invest in reducing the rate of depreciation α. For the model this does not make much difference, since in both circumstances investments contribute to increased production in the following year.

$$p_2 f(K_2) + p_2^{\mathrm{n}}(1-\alpha)K_2 = C_2 \tag{4}$$

$$K_2 = (1-\alpha)\, K_1 + I_1 \tag{5}$$

The subscripts indicate the time period ($t = 1, 2$).
Exogenous variables included in this model are:
p_t, output price; K_1, initial stock of natural capital (land); p_n^t, cost of (investing in) natural capital; ρ, rate of time preference; and, α, rate of capital depreciation.
Endogenous variables are: C_t, consumption in period t; I_1, investments in period 1; and, K_2, capital stock at the beginning of period 2.

Assuming an interior solution, the maximization problem can be solved using the Lagrange method

$$L{=}U(C_1) + \frac{U(C_2)}{1{+}\rho} - \mu_1\Big[p_1 f(K_1) - C_1 - p_1^{\mathrm{n}}(K_2 - (1-\alpha)K_1)\Big] - \mu_2\Big[p_2 f(K_2) + p_2^{\mathrm{n}}(1-\alpha)K_2 - C_2\Big]$$

This results in the following first-order conditions

$$\frac{\partial L}{\partial C_1} = \frac{\partial U}{\partial C_1} + \mu_1 = 0 \tag{6}$$

$$\frac{\partial L}{\partial C_2} = \frac{\partial U}{\partial C_2}\,\frac{1}{1+\rho} + \mu_2 = 0 \tag{7}$$

$$\frac{\partial L}{\partial K_2} = 0 \Rightarrow p_2 \frac{\partial f(K_2)}{\partial K_2} = \frac{\mu_1}{\mu_2} p_1^n - p_2^n(1-\alpha) \tag{8}$$

Conditions (6) and (7) imply

$$\frac{\partial U(C_1)/\partial C_1}{\partial U(C_2)/\partial C_2}\,(1+\rho) = \frac{\mu_1}{\mu_2} \tag{9}$$

or, the marginal rate of intertemporal substitution of consumption multiplied by 1 plus the pure rate of time preference, equals the ratio of variables associated with the two consumption constraints. In the following the function $h(C_1,C_2)$ is defined to represent the marginal rate of intertemporal substitution $\frac{\partial U(C_1)/\partial C_1}{\partial U(C_2)/\partial C_2}$. This function is decreasing with respect to C_1 and increasing with respect to C_2. This follows from the strict concavity of the subutility functions

$$\frac{\partial h(C_1, C_2)}{\partial C_1} < 0 \text{ and } \frac{\partial h(C_1, C_2)}{\partial C_2} > 0$$

Now, after rearrangement the following three equations determine the levels of optimal natural capital K_2 and consumption levels C_1 and C_2 for the farm household if the household does not have access to credit

$$p_1 f(K_1) - C_1 - p_1^n(K_2 - (1-\alpha)K_1) = 0 \tag{10}$$

$$p_2 f(K_2) + p_2^n (1 - \alpha) K_2 - C_2 = 0 \tag{11}$$

$$\frac{p_2 df(K_2)}{\partial K_2} - (1 + \rho) h(C_1, C_2)\, p_1^n + p_2^n (1 - \alpha) = 0 \tag{12}$$

Since the household is credit constrained these three equations jointly determine the household's response to exogenous changes in prices. These responses are derived theoretically in the next section.

4. Changes in the price of land and output in the presence and absence of credit markets

One way to preserve natural capital suggested by cost–benefit analysis is to increase the (future) value of land or of its output, on the premise that additional investments in soil conservation will be induced by the increased return on these investments. Increasing the price of natural capital can be realized by improving the market for land in such a way that the demand for land increases. The provision of tradable property rights is one potential step in this direction. In many countries, land acquisition possibilities are restrained by traditional law, effectively forbidding outsiders to obtain land, or by governments preventing foreigners to acquire land. Other means to increase the demand (and hence the price of natural capital) are abolishing taxes on the transfer of land, eliminating bureaucratically determined prices, or reducing tenure insecurity. Increasing population pressure will also increase the demand for land. All these channels have been advanced as potential means to prevent land degradation (Ervin, 1986; Wachter, 1992; Tiffen, Mortimore, and Gichuki, 1994; Hayes, Roth, and Zepeda, 1997). Another way to induce investments in soil conservation, at least according to cost–benefit analysis, is by increasing the future price of agricultural output. In view of the many distortions that exist for output prices, this can be brought about by abolishing fixed prices by marketing boards (assuming that they are fixed below market prices) or by reducing export taxes. Changes in the agricultural policies of the EU and the US leading to higher world market prices for agricultural produce have also been advanced as ways to ensure the protection of fertile agricultural land. The question now is whether these suggestions for soil conservation also hold in a context characterized by malfunctioning credit markets.

To explore this, first consider the effect of a foreseen increase in the price of land in the absence of credit markets. This effect is determined simultaneously by the equations (10), (11), and (12). Applying the implicit function theorem, differentiating with respect P_1^n to and applying Cramer's rule gives

$$\frac{\partial K_2}{\partial p_2^n} = \frac{1}{|A|}(-(1 - \alpha)) + \frac{1}{|A|}(1 - \alpha) K_2 \left(\frac{\partial h(C_1, C_2)}{\partial C_2} \right) (1 + \rho) p_1^n \tag{13}$$

where $|A|$ is the determinant of the matrix which is negative by assumption (appendix). Given that $|A|$ is negative, the overall effect on investments in soil conservation following a perceived price change in the second period for land is ambiguous as the sign of the first factor of equation (13) is positive and of the second negative. This result can be explained intuitively as the first factor indicates that investments in soil protection increase when the marginal return to the sale of natural capital (land) is higher but decrease when an increase in the second period consumption goes at the expense of first period consumption.

Next the farmers' response to investments in natural capital in the expectation of higher agricultural output prices is determined in a similar fashion. Now we get

$$\frac{\partial K_2}{\partial p_2} = \frac{1}{|A|}\frac{-\partial f(K_2)}{\partial K_2} + \frac{1}{|A|} f(K_2)\frac{\partial h(C_1, C_2)}{\partial C_2}(1 + \rho)p_1^n \tag{14}$$

Again the result is ambiguous: the first term of equation (14) is positive but the second is negative. Investments in soil protection increase when the marginal return to capital is higher (the first term) but decrease when an increase in the second period consumption goes at the expense of first period consumption. In both instances, the trade-off between current and future consumption levels results in a unpredictable household response to increases in future land or agricultural output prices.

Next a credit market is introduced in a way that allows farm households to access it. Does the model then provide responses which are in line with predictions made by cost–benefit analysis?

If a credit market is incorporated in the model, equations (1) to (4) have to be changed to include the fact that money can be borrowed or lent at the market rate of interest (r) and has to be repaid with interest, or is returned with interest later. The *total amount borrowed* in period t is indicated in the revised model by D_t. Dependent on whether a household has savings or is indebted, D_t is smaller or greater than zero. We start from the premise that at the beginning of the first period, the household does not hold any debt or savings. In period 1—equation (16)—the household is able to increase the funds available to it or to set aside savings. In the second period interest payments have to be made or are received. The closing condition is that the household does not hold any debts or savings at the end of the second period. The model now becomes

maximize

$$U = U(C_1) + \frac{U(C_2)}{1 + \rho} \tag{15}$$

subject to

$$p_1 f(K_1) + D_1 = C_1 + p_1^n I_1 \tag{16}$$

$$p_2 f(K_2) + p_2^n(1 - \alpha)K_2 - D_1 = C_2 + rD_1 \tag{17}$$

$$K_2 = (1 - \alpha)K_1 + I_1 \tag{18}$$

How does this affect the household's response to anticipated increases in agricultural output or land prices? Solving the first-order conditions of the Lagrangian we get

$$\frac{\partial U(C_1)/\partial C_1}{\partial U(C_2)/\partial C_2}(1 + \rho) = 1 + r \tag{19}$$

$$\frac{\partial L}{\partial K_2} = 0 \Rightarrow \frac{p_2 \partial f(K_2)}{\partial K_2} = (1 + r)p_1^n - p_2^n(1 - \alpha). \tag{20}$$

which is basically identical to equations (8) and (9) but with (μ_1/μ_2) replaced by $(1 + r)$. In equations (19) and (20) the interest rate r plays a dual role. It determines the investment decision of (20) and the allocation of consumption over time (19), but thanks to the possibility to borrow the household can separate its consumption and investment decisions. Hence it can first decide on the natural capital stock it desires—which of course is done in a way such that the marginal return to capital in the second period $\frac{p_2 \partial f(K_2)}{\partial K_2}$ equals the cost of capital $(1 + r)p_1^n - p_2^n(1 - \alpha)$, after which it allocates the resources for consumption between the two periods—of course such that the marginal rate of substitution equals the market rate of interest plus one $(1 + r)$.

It follows that in the presence of credit markets the farm household responds to changes in prices as if it were a profit-maximizing producer. Investment decisions are no longer affected by competitive demands for resources for household consumption. The effect of a change in land or agricultural output prices on the natural capital stock in period 2 can now be derived directly from (20) by applying the implicit function theorem (Varian, 1984). We get

$$\frac{\partial K_2}{\partial p_2} = -\left[\frac{p_2 \partial^2 f(K_2)}{\partial K_2^2}\right]^{-1} \frac{\partial f(K_2)}{\partial K_2} \tag{21}$$

and

$$\frac{\partial K_2}{\partial p_2^n} = -\left[\frac{p_2^n \partial^2 f(K_2)}{\partial K_2^2}\right]^{-1} \frac{\partial f(K_2)}{\partial K_2} \tag{22}$$

Given that the production function is strictly concave equations (21) and (22) always generate positive responses to increases in the prices of land or output in the second period. Thus in the presence of credit markets no perverse responses occur and the household behaves in a standard, profit-maximizing manner. Only in this situation standard cost–benefit results are obtained.

5. Why may standard cost–benefit analysis be inappropriate?

The above results show that in the absence of credit markets and even if the future discounted benefits of investment increase, the household may actually be *less inclined* to invest. In this case standard cost–benefit analysis would suggest the opposite because investment becomes more attractive (B_t increases in formula (1)). This holds for any *exogenously given* discount rate, whether it is the market rate of interest or a household-specific shadow price of time. Hence, cost–benefit analysis will not always be appropriate as a model of household investment behavior.

The reason why standard cost–benefit analysis may be inappropriate is that it is typically assumed that the discount rate is given. First an appropriate discount rate is determined, after which the costs and benefits of the different investment options are compared. In this paper we show that there are circumstances where this will be problematic, because the discount rate is affected by price changes.

To see this more clearly, consider the discount rate. For the model without credit market it can be derived as follows.[3] The indirect utility function $V(.)$ of a household for given level of investment is given by substitution of equations (2)–(4) in equation (1)

$$V(p_1, p_2, p_1^n, p_2^n, I_1, K_1) =$$

$$U(p_1 f(K_1) - p_1^n I_1) + \frac{U(p_2 f((1-\alpha)K_1 + I_1) + p_2^N (1-\alpha)((1-\alpha)K_1 + I_1))}{1+\rho}$$

Differentiation of $V(.)$ with respect to investment I_1 gives

$$\frac{\partial V}{\partial I_1} = -\frac{\partial U}{\partial C_1} p_1^n + \frac{1}{1+\rho}\frac{\partial U}{\partial C_2}\left(p_2 \frac{\partial f}{\partial K_2} + p_2^n (1-\alpha)\right)$$

The first term gives the marginal cost of investment, weighted by the marginal utility of consumption in the first period, while the second term gives the discounted marginal future benefit of investment, weighted by the marginal utility of consumption in the second period. If we divide by the marginal utility of consumption in the first period to obtain an expression in terms of money instead of utility, we get:[4]

$$\frac{\partial V/\partial I_1}{\partial U/\partial C_1} = -p_1^n + \frac{1}{1+\rho}\frac{\partial U/\partial C_2}{\partial U/\partial C_1}\left(p_2 \frac{\partial f}{\partial K_2} + p_2^n (1-\alpha)\right)$$

$$= -p_1^n + \frac{1}{1+\rho^*}\left(p_2 \frac{\partial f}{\partial K_2} + p_2^n (1-\alpha)\right) \tag{23}$$

where ρ^* is the appropriate discount rate for the household. Expression (23) again gives the cost–benefit criterion of equation (1): an investment should be undertaken if the monetary cost of investment (p_1^n) exceeds the discounted monetary benefits of investments $\left(p_2 \frac{\partial f}{\partial K_2} + p_2^n (1-\alpha)\right)$. The appropriate discount rate is a function of the pure rate of time preference ρ and the marginal rate of intertemporal substitution of consumption

$$\rho^* = h(1+\rho) - 1.$$

The discount rate will be a function of prices. If future prices of output or land increase, the discount rate will increase at any given investment level

[3] Johansson and Löfgren (1989) use a similar method to derive cost–benefit rules for the case of disequilibrium cost–benefit rules.

[4] This expression is equivalent to equation (12).

(C_2 increases (eq. (4)) and) $\partial h(C_1, C_2)/\partial C_2 > 0$), thereby discouraging further investment. Although price increases of land or output imply greater monetary benefits of investments $\left(p_2 \frac{\partial f}{\partial K_2} + p_2^n (1 - \alpha) \text{ increases}\right)$, the net benefit will be ambiguous because of a *ceteris paribus* increase in the discount rate (ρ^*) (eq. (23)). Hence, in the presence of credit market imperfections, standard cost–benefit analysis based on a pre-determined discount rate does not automatically lead to correct prescriptions.

In case there is a perfect credit market, the discount rate will be given and equal the interest rate (see equation (19))

$$\rho^* = h(1 + \rho) - 1 = 1 + r - 1 = r$$

In this case the discount rate is independent of prices, and standard cost–benefit analysis based on a given discount rate will be appropriate. The example given in table 1 illustrates this point.

Although there is now a literature extending cost–benefit analysis to environments with market imperfections and/or disequilibrium effects (Holden, Shiferaw, and Wik, 1998; Johansson, and Löfgren, 1989), this literature does not address the issue that the appropriate discount rate may vary with prices. This paper shows that price-dependent discount rates may reverse recommendations made on the basis of standard cost–benefit analysis (which uses a given discount rate).

6. An empirical case study from the Atacora region in Bénin

In this section we discuss an empirical case study to illustrate the above findings. The intertemporal model shows that the investment responses of farm households which are liquidity constrained may even be perverse, with higher output and/or land prices leading to less soil conservation investment. Households which are not liquidity constrained should exhibit the expected investment response to higher prices. In our case study we will show that such perverse investment responses do indeed occur, *and* only for households which have not borrowed in the past but who do indicate a need for credit. The reason why they have not borrowed is that it was difficult to find somebody to borrow from, the interest rate was too high, fear of not being able to repay the debt, fear of imprisonment in case of default, or of being too old to borrow. Because these households were arguably liquidity constrained (willing but unable to borrow), this finding does lend support to the theoretical model in the paper.

The case study is drawn from a broader research program on the 'Agricultural Transition towards Sustainable Tropical Land Use', financed by the Netherlands Organisation for Scientific Research (NWO) Programme on 'Environment and the Economy'. Within the Atacora region in the North-West of Bénin, four villages were visited during a survey in 1999, and within each village approximately 25 farm households were randomly selected and interviewed. Research villages were selected on the basis of population density (from densely to sparsely populated) and distance to major market places in travel time (both far to nearby market place). The interviews collected a large amount of information on

Table 2. *General characteristics of survey villages*

	Takouanta	*Okouaro*	*Kounakogou*	*Koutagou*
Travel time home to nearest market				
(Median time in minutes)				
(a) by foot	90	20	90	90
(b) by bike	60	20	60	53
Population density per km^2 (1992)	13.6	65.7	64.2	126.3
Number of households (1992)	87	125	162	176
Average household size	5.04	6.80	6.12	7.02
Average plot size (ha)	0.71	0.65	0.66	0.47
Average number of plots/household	5.84	6.68	4.08	4.20
Percentage of plots with steep slope	47	4	8	25
Major types of soil				
(% of plots)				
(a) rock	40	2	8	51
(b) gravel	38	21	68	29
(c) sand/loam	21	74	24	15
(d)other	1	3	0	5
Major land conservation investments				
(% of plots)				
(a) stone bunds	59	0	2	55
(b) tie-ridging (type 1)	33	14	72	27
(c) tie-ridging (type 2)	1	1	19	2

Source: Survey.

demographics, the farming system, and soil and water conservation investments of the household (Gandonou and Adégbidi, 2000). Table 2 provides information on a number of general characteristics of the villages.

Within the four study villages three major land conservation investments can be observed.[5] Stone bunds are usually found in villages where rocky soils are predominant, namely Takouanta and Koutagou. In these two villages 59, respectively 55 per cent of the plots have stone bunds. Tie-ridging and ridging are widely used in all the study villages and might be seen as the most popular soil and water conservation techniques in the region. They are broadly used and more elaborately in the plains where gravelly soils and light to high slopes are predominant (Kounakogou). Most of the crops are planted on ridges except yam which is grown on mounds (in the bottomlands).

Two versions of the tie-ridging techniques are available. The first one is known under the local name '*spenpen*';[6] in this version, most of the ridges are parallel to the slope but they are intersected by a certain number of

[5] See Adégbidi, Gandonou, and Oostendorp, (2000) for an extended discussion of each of these land conservation techniques.

[6] This device is called '*billonnage cloisonné*' in French.

bunds which are perpendicular to the slope. The second version of tie-ridging is often found on steep plots. Like the former version, the ridges are also parallel to the slope; however, there are at least two rows of ridges on each plot instead of one row as observed in the previous version.

Because the first version of tie-ridging is the dominant form of land conservation investment, and is well-represented in each of the villages, we limit our discussion to this type of land investment. These investments have large effects on productivity (Adégbidi, Gandonou, and Oostendorp, 2000).[7] Also, unlike stone bunds, the ridges are fully reconstructed every year. The reconstruction work consists in removing the old ridges and building new ones in the furrows. According to our intertemporal model, investment responses of farm households which are liquidity constrained may be perverse, with higher output and/or land prices possibly leading to less soil conservation investment. Households which are not liquidity constrained should exhibit the expected investment response to higher prices. We therefore run two separate investment models, one for households which did not borrow in the past year but who indicated a need for credit, and one for households which did borrow or which indicated no need for credit. Households which did not borrow while indicating a need for credit are arguably liquidity constrained, while household which did borrow or indicated no need for credit are not.[8] A pooling test is used to check whether it is indeed appropriate to use two rather than one investment model. Investment is modelled at the plot-level by whether any tie-ridging investment has taken place on the plot.

Because we have a cross-sectional dataset, we cannot use output prices to identify price responses. But we do know the distance between the plot and the 'tata' (homestead) and distances affect the net output price through transaction costs (particularly transportation costs). Hence, crops grown on plots which lie further from the tata will typically face lower output prices (assuming that most of the produce is first transported to the tata and next to the market), and we can use plot differences in distance to identify price responses. Distance further affects the price of investment and the price of land, because the cost of an investment on a plot may be higher if the plot is further away (perhaps due to higher labour costs) and because the NPV of future crops grown on the land is lower because of lower net output prices.[9] Hence besides lower net output prices, plots further from the tata face higher investment cost and lower land prices, further discouraging investment. In the following we focus on the combined price response from each of these prices.

[7] The investment rationale of stone bunds is also more difficult to asses as almost all of them have been built by 'ancestors' (although maintenance still takes place). Besides conserving soil and water they also function as property demarcations.

[8] This is also called 'loan-rationing' in the literature. Here we ignore another type of credit constraints, namely 'size-rationing' (i.e. households may borrow but they are constrained in the size of the loan).

[9] The investment and land prices in the model are given by p_1^n and p_2^n respectively (see eqs. (3) and (4)).

The distance from the tata to the market is modelled as household-specific effect

$$\Pr[I_{hp} = 1] = \alpha_h + \beta d_{hp} + X_{hp}\gamma + \epsilon_{hp}$$

where I_{hp} is an indicator variable which equals 1 if household h has done any tie-ridging investment on plot p, α_h is a household-specific effect, d_{hp} indicates the distances from plot p to the tata of household h, X_{hp} is a vector of other explanatory variables, and ϵ_{hp} is a disturbance term. The parameter β gives the price response.

The intertemporal model has the following implications for the price response parameter β:

$$\beta = \begin{cases} <> 0 & \textit{credit constrained} \\ < 0 & \textit{not credit constrained} \end{cases}$$

For plots used by households who receive no credit while indicating a need for it (credit constrained) we expect an ambiguous price response on investment. For plots used by households receiving credit or indicating no need for it we expect a response in accordance with standard cost–benefit analysis—plots with lower net output and land prices and higher investment prices (that is further away from the tata) receive less investment.

Besides including the distance variable, we also include a number of other explanatory variables in the regression which may affect the willingness to invest (see for instance Shiferaw and Holden, 1998; Pender and Kerr, 1998; Neill and Lee, 1999; Shively, 2001). Failure to include these other variables may lead to a biased price response estimate because of omitted variables bias. Plot slope is included because steeper slopes (particularly where rainfall is high) increase the incentive to invest in land protection and to adopt less-erosive forms of land use. Soil type is included to control for differences in the erodibility of the soil. The number of plots owned by the household and the size of the plot are also included. We expect that as farm fragmentation increases farmers will have less incentive to make land improvements because of higher transaction costs. Larger plots are more likely to receive investments if there are fixed costs to investment on a plot, such as transportation costs. Plot fertility is also included in the regression as the incentive to investment is higher for less fertile plots.[10] The availability of labour and/or capital will also affect investment if labour and/or credit markets are imperfect (Pender and Kerr, 1998). We therefore include the number of household members and the number of livestock in the household (in tropical livestock units). A dummy whether the plot is borrowed is also included as farmers may be less willing to invest in plots not owned. Finally village dummies are included to control for village-specific factors possibly affecting investment, such as the quality of the infrastructure, social and administrative conditions in the village, and differences in rainfall.

The regression model is estimated as logit, and the household-specific

[10] Plot fertility is measured as whether the farmer has indicated that the plot belongs to the top half of the most fertile plots within the household.

Table 3. *Price elasticity and liquidity constraints (t-values in parentheses)*

	Constrained households	*Unconstrained households*
Price elasticity	−0.09	−0.22
	(0.67)	(2.28)
Number of plots	294	215
Pseudo R^2	0.31	0.19

Note: the elasticity is calculated as the average elasticity of the probability of investment with respect to the distance variable.

effects have been modelled as random effects. A Hausman test does not reject random effects against fixed effects. A Chow test has been performed to test whether the sample should be split, and is significant at a level of 0.058. This indeed suggests that credit constrained households behave differently from non-constrained households.[11] Table 3 reports the price elasticity for households which are credit constrained and which are not credit constrained.

The table shows an ambiguous (not significantly different from zero) price response for households which did not borrow in the past and which did not indicate a need for credit. Households which did borrow or indicated no need for credit show the expected price response. Hence, our case study does lend support to the theoretical model in the paper.

7. Conclusions

Starting from the observation that many farm households, and especially those in developing countries, are credit constrained this paper investigates the reliability of cost–benefit predictions on the attractiveness of soil conservation projects. We show that contrary to the predictions of cost–benefit analysis, higher prices for agricultural produce or land do not have to result in unambiguous investment responses in soil conservation. We find that an increase in the NPV for a conservation project is no indisputable indication of whether a farm household will be more likely to adopt the project. In fact, even perverse investment reactions to increased price incentives cannot be excluded. Whether or not such responses occur is an empirical matter. Our case study from the Atacora region in Bénin suggests that they arise indeed. It follows that, in the absence of credit markets, cost–benefit results have to be interpreted with care in determining whether a given investment project is attractive for farmers.

An immediate policy implication of our results is that the likelihood of a positive conservation response to increased prices is enhanced when higher land or agricultural output prices are accompanied by the pro-

[11] First a regression is run with all households on all variables and a dummy for those that are credit constrained, plus all variables interacted with this dummy. The Chow test is calculated as a likelihood ratio test on whether the two groups are significantly different, i.e. whether the coefficients on the credit dummy and all the variables interacted with this dummy are jointly significantly different from zero.

vision of access to credit. An additional implication is that of the many policies that could lead to enhancing investments in soil conservation—varying from increases in the demand for land to the abolishment price controls on agricultural produce—the introduction of credit markets should be considered as well. Especially if one intends to induce the poor to invest in soil conservation, introducing credit markets is an important consideration.

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Appendix

Applying the implicit function theorem and differentiating with respect to p_2^n yields

$$\begin{bmatrix} -p_1^n & -1 & 0 \\ p_2\dfrac{\partial f(K_2)}{\partial K_2} + p_2^n(1-\alpha) & 0 & -1 \\ p_2\dfrac{\partial^2 f(K_2)}{\partial K_2^2} & -(1+\rho)p_1^n\dfrac{\partial h(C_1, C_2)}{\partial C_1} & -(1+\rho)p_1^n\dfrac{\partial h(C_1, C_2)}{\partial C_2} \end{bmatrix} \begin{bmatrix} \dfrac{\partial K_2}{\partial p_2^n} \\ \dfrac{\partial C_1}{\partial p_2^n} \\ \dfrac{\partial C_2}{\partial p_2^n} \end{bmatrix}$$

$$= \begin{bmatrix} 0 \\ -(1-\alpha)K_2 \\ -(1-\alpha)] \end{bmatrix}$$

Using Cramer's rule one gets equation (13)

$$\frac{\partial K_2}{\partial p_2^n} = \frac{1}{|A|}(-(1-\alpha)) + \frac{1}{|A|}(1-\alpha)K_2\left(\frac{\partial h(C_1, C_2)}{\partial C_2}\right)(1+\rho)\, p_1^n$$

The determinant is equal to

$$p_2\frac{\partial^2 f(K_2)}{\partial K_2^2} - \left(p_2\frac{\partial f(K_2)}{\partial K_2} + p_2^n(1-\alpha)\right)\left(\frac{\partial h(C_1, C_2)}{\partial C_2}\right)(1+\rho)p_1^n$$
$$+ \left(\frac{\partial h(C_1, C_2)}{\partial C_1}\right)(1+\rho)(p_1^n)^2$$

It is negative by assumption. This follows from the strict concavity of the production function and the subutility functions which induces the first term to be negative, the second positive (before it is multiplied by -1) and the third to be negative again.